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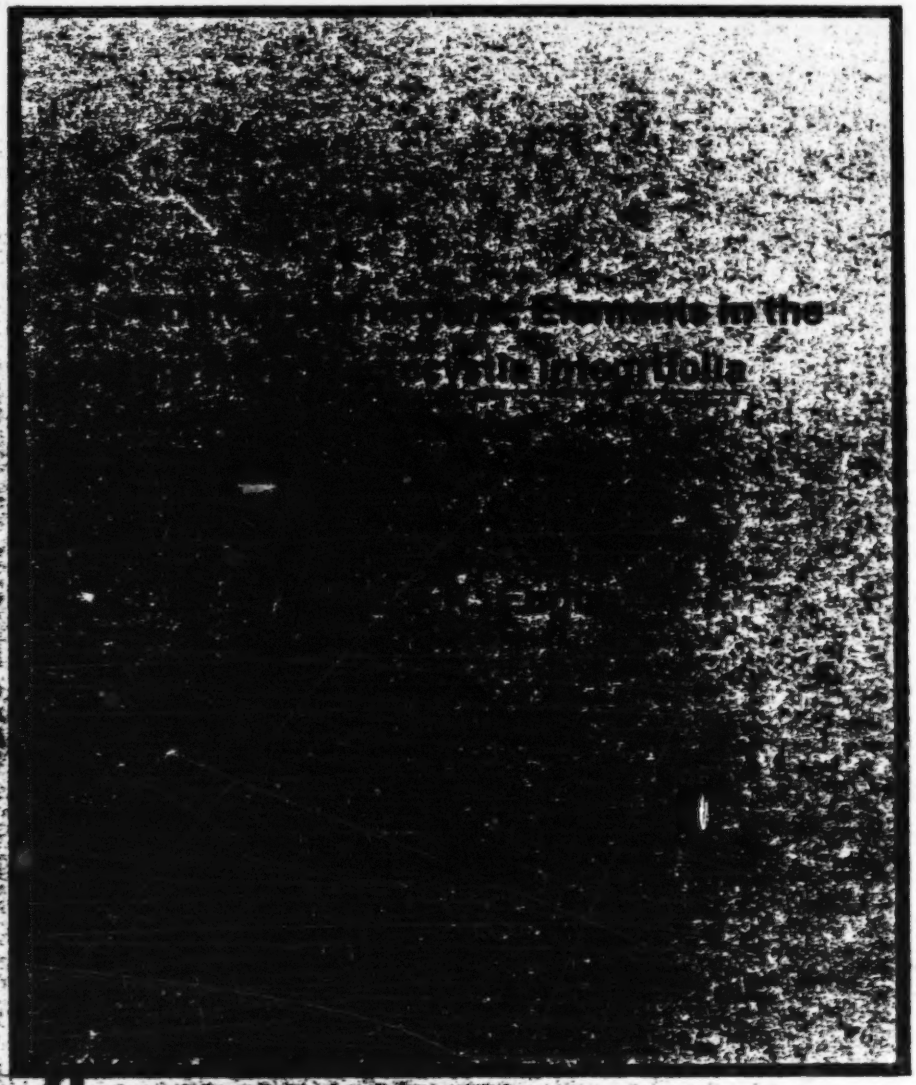

FISHERIES AND MARINE SERVICE
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TECHNICAL REPORT No. 695
RAPPORT TECHNIQUE N° 695

1978

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TECHNICAL REPORT NO.

695

(Numbers 1-456 in this series were issued as Technical Reports of the Fisheries Research Board of Canada. The series name was changed with report number 457)

RAPPORT TECHNIQUE No.

695

(Les numéros 1-456 dans cette série furent utilisés comme Rapports Techniques de l'office des recherches sur les pêcheries du Canada. Le nom de la série fut changé avec le rapport numéro 457)

The Content of Inorganic Elements in the Marine Alga *Macrocystis integrifolia* Over the Growing Season

by

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This is the fortieth Technical Report from the Research and Development Directorate Vancouver Laboratory Vancouver, B.C.

Ceci est le quarante Rapport de la Direction de la Recherche et Vancouver Vancouver, (C.-B.)

1976

RÉSUMÉ

L'introduction du présent rapport donne une description détaillée de l'algué marine Macrocystis integrifolia de la côte de la Colombie-Britannique et traite de son cycle vital.

L'algue a été recueillie à des intervalles d'un mois au cours de la saison de croissance, et 18 éléments minéraux, les matières solides et les cendres ont été sodés. Les éléments les plus abondants étaient, par ordre décroissant, le potassium, le sodium, le calcium, le magnésium, le phosphore, le strontium, le fer, le bore, l'aluminium, le baryum, le zinc, le chrome, le manganése, le cuivre, le plomb, le cobalt et le mercure. Les fluctuations saisonnières dans leur concentration au cours de la saison de croissance sont indiquées, et il est question de l'utilité commerciale de cette teneur en minéraux.

ABSTRACT

The introduction to this report presents a detailed description and life history of the marine brown alga Macrocystis integrifolia as it occurs on the coast of British Columbia.

The alga was collected at monthly intervals over the growing season and analyzed for eighteen inorganic elements, solid matter and ash. Contained in the alga were the following elements in decreasing order of abundance: potassium, sodium, calcium, magnesium, phosphorus, strontium, iron, boron, aluminum, barium, zinc, chromium, manganese, copper, cadmium, lead, cobalt and mercury. The seasonal variations in the concentrations of these elements in the plant throughout the growing season are presented and the commercial utility of this mineral content discussed.

KEY WORDS:

Brown alga, Macrocystis integrifolia, cation content, seasonal variation, kelp utilization.

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INTRODUCTION

The genus Macrocystis belongs to the Phylum Phaeophyta, Class Heterogeneratae, Order Laminariales and is in the family Lessoniaceae. Three species are generally recognized in the world, Macrocystis pyrifera (Linnaeus), C.A. Agardh, Macrocystis angustifolia, Bory, and Macrocystis integrifolia, Bory (Womersley, 1954) and their distribution ranges to the coastal regions of Peru, Chile, Patagonia, Tierra del Fuego, Tasmania, South Australia, South Island of New Zealand, the Cape region of South Africa and circum subantarctica.

In North America the genus occurs only on the Pacific Coast, with Macrocystis integrifolia extending from Kodiak Island in Alaska to the Monterey Peninsula, California (Druehl, 1970), Macrocystis pyrifera extending from Point Conception, California to Punta San Hipolito in Baja California (North, 1971), and Macrocystis angustifolia overlapping the other two species from Santa Cruz to San Clemente in California. Differentiation of the species is based on the holdfast characteristics, with rhizomatous branches occurring only in the holdfasts of Macrocystis angustifolia and Macrocystis integrifolia and haptera emerging from the edges only, not all sides, of the strongly flattened rhizomatous branches in the latter species (Neushul, 1971).

Macrocystis integrifolia is the only species of this genus on the coast of British Columbia (Scagel, 1947), although phenotypic variants of this species have been observed depending on the different environmental habitats in which the alga resides (Lobban, 1976). The plant, Figure 1, which is one of the largest brown algae on the coast of British Columbia, yet the smallest of the three Macrocystis species, has a holdfast which consists of dichotomously branched rhizomes 2-4 cm. wide from which numerously branched haptera emerge to retain the plant to the rocky substrate. The many cylindrical stipes rising from the rhizomes are up to 1.3 cm. in diameter and 20 metres long. The leaf-like lanceolate laminae, up to 35 cm. long and 5 cm. wide, are formed at fairly regular intervals, up to 18 cm. apart, and become progressively smaller and closer together towards the terminal laminae or apical scimitar where they are differ-

entiated initially. The progressive stages of separation of the laminae from this terminal growing point are illustrated in the Figure 1 insert. On a mature stipe which is close to the surface of the water, as many as 25 to 30 laminae may be in progressive stages of differentiation. The laminae have irregular furrowed surfaces, are denticulated at the edges and are attached at the proximal end to the stipe by a spherical to oval float known as a pneumatocyst, which can be up to 5 cm. long and 2.5 cm. in diameter. Usually the lower 1-2 metres of a mature stipe is devoid of laminae, having become senescent or damaged by predation or wave action. Located towards the lower attachment of the stipes to the holdfast are fertile laminae known as sporophylls which contain reproductive cells known as sporangia. The life-cycle of Macrocystis involves the release of motile zoospores from the mature sporangia which eventually settle on the sea bottom and develop into male and female gametophytes. The spermatozoid from the antheridium of the male gametophyte fertilizes the egg in the oogonium of the female gametophyte, resulting in the formation of a zygote. Repeated cell division of this zygote affords the young sporophyte with an undivided blade which undergoes further splitting and rapid development, resulting in the formation of the mature plant. Macrocystis is a perennial plant with major growth occurring from early spring to the end of October (Lobban, 1976), with the period from July to September tending to be the most active for zoospore release from mature sporophylls (Scagel, 1947).

Macrocystis integrifolia is not as abundant on the coast as Nereocystis luetkeana and tends to grow in areas exposed to open ocean. The species found on this coast usually occurs inside a protective fringe of Nereocystis and grows on rocky substrate from a zero tide level down to a depth of about 10 metres. The plant can exceed 33 metres in length and weigh 50 kg., and the major stipes may grow as much as 5 cm. per day under favourable conditions (Scagel, 1961).

Although extensive use has been made of the Macrocystis pyrifera resource in California, and elsewhere in the world, as a source of chemicals such as alginates - for use in industrial and food items - and trace

elements - for use as a dried meal product in livestock feeds and fertilizer bases (Levring et al., 1969), the species on the coast of British Columbia has remained untouched. To appreciate the commercial chemical significance of this renewable resource, a systematic study of the chemical nature of Macrocystis integrifolia has been performed and in this, the first of a series of reports, data are presented on the elemental composition of the alga over a study period April to October. This data will complement the information acquired on the chemical composition of the other giant floating kelp on the Pacific coast of Canada, namely Nereocystis luetkeana (Whyte et al., 1974(a), 1974(b), 1975(a), 1975(b) and 1975(c)).

EXPERIMENTAL

(a) Collection and Preparation of Specimens

Samples of Macrocystis integrifolia were collected from selected kelp beds at Parsons Spit, Sooke, Vancouver Island, in the middle of the months April through October. The stipes were cut approximately 2 metres from the apical end, only from healthy attached plants and, to avoid enzymatic and microbiological degradation, the specimens placed in plastic bags were transported to the laboratory in insulated coolers, the bottoms of which were covered with crushed solid carbon dioxide over which a layer of ordinary ice was spread. The plants in the laboratory cold room were freed from any extraneous epiphytes and epifauna, blotted lightly with paper to remove any excess surface water, then packaged in zip-lock plastic bags and stored at -31°C. Subsequent freeze drying of the specimens afforded dry alga which was ground with a porcelain mortar and pestle to 20 mesh size. Each lot analyzed contained portions from at least ten plants collected at the same time and, for the period of the analysis, the ground samples were stored in the freeze dryer to ensure anhydrous conditions at all times.

(b) Methods of Analysis

1. Dry Weight

Samples were frozen at -31°C. and dried to constant weight in a freeze dryer. After recording the weight the samples were ground to pass a 20 mesh sieve.

2. Ash Content

Samples of the dry alga were ignited in an electric muffle furnace at 500°C. for 20 hours; increased temperatures resulted in the loss of volatile minerals.

3. Insoluble Ash Content

The content was determined by measuring the residual material after hot water leaching of an ashed sample.

4. Elemental Analysis

The cations were determined by emission spectroscopy with the exception of cadmium, cobalt and lead which were analyzed by atomic absorption spectrophotometry, and mercury which was analyzed by cold vapour atomic absorption.

All percentages, with the exception of dry weights, are based on absolutely freeze dried weights.

RESULTS AND DISCUSSION

The specimens of Macrocystis integrifolia were collected in the Strait of Juan de Fuca at Sooke from April to October of the same year. Although the alga is perennial from the holdfast, the prominent growth in the plant has been observed to occur within this collection period (Lobban, 1976) and the algae at Sooke after October were noted to become increasingly susceptible to the encrusting bryozoan Membranipora membranacea.

The samples for analysis were not washed with fresh water since it has been demonstrated that inorganic salts, principally those of potassium and sodium, were leached from the algae by this treatment (Young et al., 1958). Similarly, the ready replacement of potassium with sodium ions was indicated when macerated algal tissue was slurried in sea water (Whyte et al., 1974(a)). To preclude any problem of metallic contamination, the grinding of the freeze dried algal samples was performed with a porcelain mortar and pestle. Unlike the study of Nereocystis luetkeana (Whyte et al., 1974(b)) the laminae and stipes of the alga were not analyzed separately since the laminae and adjoining pneumatocyst constitutes the major mass of the Macrocystis plant. Any separation of these segments of the alga on a commercial scale would be completely impractical.

All values of the content of cations in the alga are expressed as percentages or parts per million (ppm) of the absolute dry alga. As the average moisture level of the alga was 87.38%, the concentration of elements in the fresh plant will be approximately 0.1262 times the values quoted in this report.

The figures obtained for the dry weight of alga recorded over the period studied are presented in Table 1. The solid matter in the alga varied from a minimum of 9.75% in April to a maximum of 14.47% in August, and over the growing season a mean value of 12.62% was observed.

The moisture content of the alga appeared to decline rapidly from April to May and from July to August, Figure 2, indicating that harvesting of this resource in the latter part of the season, particularly in August, would provide the highest returns of solid material per harvesting effort expended.

Almost an 8% differential in the total ash content of the alga was observed over the growing period, with the minimum level occurring in June and July followed by a general increase to a maximum content in October, Figure 3. The average total ash content of the dry alga was 39.4%, a figure derived from values contained within the range 36.3% to 43.9% registered over the collection period, Table 1. Similar fluctuations in the insoluble ash content were observed, Figure 3; however, a marked increase in the ratio of soluble to insoluble salts in the plant was evident during the month of July, Table 1. The lowest level of insoluble ash in July at 4.9% content contrasts with the 8.1% content observed in the alga collected only two months later. A seasonal average value of 6.9% was obtained for the insoluble ash content of the alga.

The most abundant elements in Macrocystis integrifolia were assessed to be potassium and sodium, with lesser amounts of calcium, magnesium and phosphorus. The major portion of the soluble ash from the alga consisted of the salts of potassium, since the seasonal average content of the cation was 13.1%. The levels of potassium fluctuated more or less in accordance with the total ash content, Figures 3 and 4, reaching peak levels in May at 13.8% and again at the end of the season in October at 16.1%, with the lowest concentration being recorded in June at 11.2%, Table 2. The next most abundant cation in the alga was sodium which ranged from 3.41% to 5.03% over the season and provided an average content of 4.14%, Table 2. Whereas the potassium content was the lowest in June, a maximum of 5.03% was observed for the sodium content of the alga collected in that month. In general, during the latter half of the

growing season the level of sodium declined in the alga, quite contrary to the increased level noted for the potassium ion, Figure 4.

The range of calcium content in the alga, 0.57% to 0.72%, was observed in the specimens collected in the months of April and May, Table 2; thereafter, no undue fluctuations in the calcium content of the alga were observed throughout the remainder of the growing season, Figure 5, and a mean value of 0.65% was obtained. Apart from the peak levels of magnesium in June at 0.67% and September at 0.57%, the content of the cation in the alga was fairly constant at approximately 0.51% for the season, Figure 5. The higher overall seasonal level of 0.54% reflected the broader range of concentrations, 0.49% to 0.67%, registered for the magnesium throughout the season, Table 2.

The content of phosphorus in the dry alga ranged from a minimum in April of 0.24% to a maximum in October of 0.48%, Table 2. The major increase in the content of this element occurred from the month of August to the end of the season, with the alga averaging a 0.34% content of phosphorus.

The minor and trace elements strontium, boron, iron, aluminum, zinc, barium, manganese, chromium and copper, which were present in Macrocystis over the growing period are recorded in Table 3. Strontium was the most abundant element of this group, having a seasonal range of 576 to 775 ppm. and an average content of 663 ppm. in the plant. The inclusion level of this cation decreased sharply from a constant level in early spring to a minimum level in September, Figure 6. This sharp decline may have been due to a marked decrease in the content of alginic acid in the alga. As sea water contains strontium in a concentration of 13 ppm (Levring et al., 1969) the corresponding high levels of this cation in Macrocystis is undoubtedly dependent on the content of the extremely selective cation exchanger alginic acid which is known to effectively sequester the strontium ion (Haug et al., 1967).

Within the range of 61 to 112 ppm. for the seasonal content of

boron, two peak concentrations were evident from the June and September samples, Figure 7. The average content of 88 ppm. for boron over the growing season was also registered for the October specimen, Table 3. A marked increase in the content of iron in the alga was exhibited by the alga having a minimum level in May at 42 ppm., which was followed by an amplification to 158 ppm. by September. Over the collection period the average iron content of the alga was 93 ppm, Table 3. The monthly fluctuations evident in the iron content of the alga were closely paralleled by the aluminum content. Minimum and maximum concentrations of both elements occurred in May and September respectively and from the graph, Figure 7, it was clear that a close relationship existed between the concentrations of iron and aluminum in the alga. Indeed, this relationship was also evident in the laminae and stipes of the other giant kelp, Nereocystis luetkeana (Whyte et al., 1974(b)). The content of aluminum varied from 38 ppm. in May to 91 ppm. in September and over the season averaged out at 62 ppm., Table 3.

In Macrocystis both levels of barium and zinc declined slightly towards the end of the season, ranging from 4 to 2 ppm. and 6 to 4 ppm. respectively. The seasonal average content for the barium at 5 ppm. and zinc at 3 ppm. in this alga was similar to the 5 ppm. for both elements observed in the stipes of Nereocystis luetkeana, yet was considerably lower than the 47 ppm. and 14 ppm. level for zinc and barium found in the corresponding Nereocystis laminae (Whyte et al., 1974(b)). Only trace amounts of manganese, chromium and copper were evident in the alga, with seasonal means of less than 4.0, 6.0, and 2.0 ppm. respectively, levels which were the limits of accuracy for the elements determined by emission spectrophotometry.

The average content of the elements detected in Macrocystis, together with the range of these elements observed over the growing season, are presented in Table 4. In addition, Table 4 includes the concentrations determined for the heavy metals cadmium, lead, cobalt and mercury present in composite seasonal samples of the alga. Only trace

quantities of cadmium and lead at 0.21 ppm. and 0.1 ppm. were detected and the concentrations of cobalt and mercury were below the detectable levels of 0.2 and 0.05 ppm. respectively in the dry alga.

The concentration of the elements in Macrocystis presented in this report indicated clearly the fluctuations in elemental composition which occurred throughout the seven month growing period. The uptake of these elements by the alga would be dependent, to a certain extent, on the elemental composition of the aquatic medium surrounding the plant (Bowen, 1966; Bryan, 1969), and this accumulation factor has been used recently to monitor environmental data related to heavy metal pollution (Butterworth et al., 1972; Fuge et al., 1973, 1974; Bryan et al., 1973; Morris et al., 1975) and for geochemical prospecting in the sea (Bollingberg, 1975). The process of accumulation of strontium has been equated with the polyanion carbohydrate content in the algae; however, it has been suggested that components such as polyphenols play an important role in sequestering other elements like zinc (Skipnes et al., 1975).

In 1971, approximately 40,000 metric tons of seaweed as kelpmeal were used throughout the world as fertilizer and fodder (Silverthorne et al., 1971). The use of kelpmeal as a trace mineral supplement in livestock feed (Jensen, 1971) generally involves the inclusion of only 2 to 5% of meal in the basal diets of the animals. The overall nutritional value of kelpmeal is lowered by the exceptionally high ash content, 36% to 44%, and provides a poor source of macronutrients, certainly for monogastric animals (Beames et al., 1976). Removal of the readily soluble potassium and sodium salts by fresh-water washing of the kelp greatly increases the organic component of kelpmeal, which apparently can be assimilated to an extent of over 50% when fed to sheep (Garrett, 1974). The ability of sheep to digest seaweed is dramatically illustrated by these ruminants on North Ronaldsay, which survive solely on seaweed growing on the foreshore of this Orkney island (Allsopp, 1974; Tribe et al., 1949).

Elements considered essential to animal nutrition: phosphorus, calcium, magnesium, sodium, iron, copper, zinc, manganese, cobalt, barium and strontium (Underwood, 1962) are all present to some extent in Macrocystis integrifolia. Minor amounts of zinc in diets of domestic animals are essential for promoting healing of wounds (Miller, 1970) and amounts of copper up to 15 ppm. in diets of pigs act as growth stimulants (Prasad, 1976)

The level of mercury in Macrocystis, at less than 0.05 ppm., was lower than that observed in Laminaria (kombu) at 0.13 ppm., Rhodymenia palmata (dulse) at 0.06 ppm., Undaria (wakame) at 0.11 ppm. and Porphyra (nori) at 0.12 ppm., all of which, as primary food products for human consumption, exceeded the World Health Organization's proposed permissible upper limit of 0.05 ppm. for food other than fish (Marderosian et al., 1972). The contents of lead, copper and zinc in the alga were considerably less than the level considered harmful in foodstuffs, viz., 10, 100 and 100 ppm. of lead, copper and zinc respectively in marine products (Canada Dept., of Health and Welfare, 1972). As the content of injurious heavy metals is significantly below the permissible upper limits for primary food items for human consumption, Macrocystis could be used with impunity for kelpmeal tablets (Seifert et al., 1956), "kombu" food items and for a herring roe on seaweed product (Dickson et al., 1972).

The use of seaweeds as a mineral source for fertilizers, either as mulches or as a hydrolyzed foliar spray, has been well documented (Burd, 1915; Booth, 1969; Blunden, 1971; Stephenson, 1968). Of the more than sixty elements which have been detected in land plants only a relative few are essential for plant development. The elements carbon, hydrogen, oxygen, nitrogen, phosphorus, sulphur, calcium, magnesium, potassium, iron, constitute the principal nutrients, and manganese, copper, chloride, zinc, boron, molybdenum the minor elements with, in special instances, cobalt, silicon and selenium (Miller et al., 1973). Many of the minor elements when present in

excess amounts tend to inhibit land plant growth; therefore, a balanced application of mineral fertilizer is critical. Thus, a dried meal from Macrocystis integrifolia, which contains most of the trace elements at benign levels, could be used as a soil conditioner having a long-lasting mineral nutrient effect or it could be hydrolysed to produce a foliar spray for more immediate plant growth stimulation.

In conclusion therefore, it would appear, based solely on the inclusion levels of the inorganic elements in Macrocystis integrifolia, that a portion of this resource on the coast of British Columbia could be utilized as a source of minerals for agricultural purposes.

REFERENCES

ALLSOPP, W., 1974. Where seaweed sheep may safely graze. The Sunday Times (London), Aug. 18, p. 5.

BEAMES, R.M., TAIT, R.M., WHYTE, J.N.C. and ENGLAR, J.R., 1976. Studies on the utilization of kelp (Nereocystis luetkeana) meal by pigs. 1. Nutrient balance experiments with growing pigs receiving diets containing from 0% to 20% kelp meal. Canadian Journal of Animal Science, in press .

BLUNDEN, G., 1971. The effect of aqueous seaweed extracts as a fertilizer additive. Proc. Intl. Seaweed Symp., 7, 584.

BOLLINGBERG, H.J., 1975. Geochemical prospecting using seaweed, shellfish and fish. Geochimica et Cosmochimica Acta, 39, 1567.

BOOTH, E., 1969. The manufacture and properties of liquid seaweed extracts. Proc. Intl. Seaweed Symp., 6, 655.

BOWEN, H.J.M., 1966. Trace elements in biochemistry, Acad. Press, London, 241 pp.

BRYAN, G.W., 1969. The absorption of zinc and other metals by the brown seaweed Laminaria digitata. Journal of the Marine Biol. Assoc., U.K., 49, 225.

BRYAN, G.W. and HUMMERSTONE, L.G., 1973. Brown seaweed as an indicator of heavy metals in estuaries in South-west England. Journal Mar. Biol. Assoc., U.K., 53, 705.

BURD, J.S., 1915. The economic value of Pacific coast kelps. Univ. of California College of Agriculture Bull., No. 248, 215 pp.

BUTTERWORTH, J., LESTER, P. and NICKLESS, G., 1972. Distribution of heavy metals in the Severn Estuary. Marine Pollution Bulletin, 3, 72.

CANADA DEPT. OF HEALTH AND WELFARE, 1972. Poisonous substances in food. Food and drug regulations, Division 15, 65.

DICKSON, F.V., BUXTON, G.A. and ALLEN, B., 1972. Propagation and harvesting of herring spawn on kelp. Technical Report, Dept. of Environment, Fisheries Service, Pacific Region No. 13, 31 pp.

DRUEHL, L.D., 1970. The pattern of Laminarialesdistribution in the northeast Pacific. Phycologia, 9, 237.

FUGE, R. and JAMES, K.H., 1973. Trace metal concentrations in brown seaweeds, Cardigan Bay, Wales. Marine Chemistry, 1, 281.

FUGE, R. and JAMES, K.H., 1974. Trace metal concentrations in Fucus from the Bristol Channel. Marine Pollution Bulletin, 5, 9.

GARRETT, W.N., 1974. Feeding value of California kelp. Final Report on Contract No. N66001-74-C-0376, U.S. Naval Undersea Centre, San Diego, Calif. (cited Food Technology, p. 27, December, 1975).

HAUG, A. and SMIDSROD, O., 1967. Strontium-calcium selectivity of alginates. Nature, 215, 757.

JENSEN, A., 1971. The nutritional value of seaweed meal for domestic animals. Proc. Intl. Seaweed Symp. 7, 7.

LEVRING, T. HOPPE, H.A. and SCHMID, O.J., 1969. Marine algae, a survey of research and utilization. Cram, De Gruyter and Co., 421 pp.

LOBBAN, C.S., 1976. Growth translocation and harvesting interactions in Macrocystis integrifolia. Final report to Marine Resources Branch, Victoria, B.C., 88 pp.

MARDEROSIAN, A.D., ULLUCCI, P. and HWANG, J., 1972. Mercury in marine algae. Proc. Food, Drugs from the Sea, p. 53.

MILLER, W.J., 1970. Zinc nutrition of cattle: a review. Journal of Dairy Science, 53, 1123.

MILLER, L.P. and FLEMION, F., 1973. The role of minerals in phytochemistry. Phytochemistry III. L.P. Miller (ed.), van Nostrand Reinhold Co., N.Y., p. 1.

MORRIS, A.W. and BALE, A.J., 1975. The accumulation of cadmium, copper, manganese and zinc by Fucus vesiculosus in the Bristol Channel. Estuarine and Coastal Marine Science, 3, 153.

NEUSHUL, M., 1971. The species of Macrocystis, with particular reference to those of North and South America. In W.J. North (ed.). The biology of giant kelp beds (Macrocystis) in California. Nova Hedwigia Heft, 32, 211.

NORTH, W.J., 1971. Introduction and background. In W.J. North (ed.) The biology of giant kelp beds (Macrocystis) in California. Nova Hedwigia Heft, 32, 1.

PRASAD, A.S., 1976. Trace elements in human health and disease. Acad. Press, p. 430.

SCAGEL, R.F., 1947. An investigation on marine plants near Hardy Bay, B.C. Report to Prov. Dept. Fisheries, 1, 70 pp.

SCAGEL, R.F., 1961. Marine plant resources of British Columbia. Bulletin Fisheries Res. Board of Canada, 127, 39 pp.

SEIFERT, G.L. and WOOD, H.C., 1956. The use of Macrocystis pyrifera as a source of trace elements in human nutrition. Proc. Intl. Seaweed Symp. 2, 107.

SILVERTHORNE, W. and SORENSON, P.E., 1971. Marine algae as an economic resource. 7th Annual Conference of Marine Technological Society, p. 523.

SKIPNES, O., ROALD, T. and HAUG, A., 1975. Uptake of zinc and strontium by brown algae. Physiol. Plant, 34, 314.

STEPHENSON, W.A., 1968. Seaweed in agriculture and horticulture. Faber and Faber, London, 231 pp.

TRIBE, D.E. and TRIBE, E.M., 1949. Sheep-grazing of seaweed, observations on North Ronaldsay, Orkney Islands, Agriculture (London), p. 416.

UNDERWOOD, E.J., 1962. Trace elements in human and animal nutrition. Acad. Press, N.Y., 429 pp.

WHYTE, J.N.C. and ENGLAR, J.R., 1974 (a). Commercial kelp drying operation at Masset, 1973. Fisheries Research Board of Canada, Technical Report No. 453, 30 pp.

WHYTE, J.N.C. and ENGLAR, J.R., 1974(b). Elemental composition of the marine alga Nereocystis luetkeana over the growing season. Fisheries and Marine Service Technical Report No. 509, 29 pp.

WHYTE, J.N.C. and ENGLAR, J.R., 1975(a). Estimation of the halogen content of the marine alga Nereocystis luetkeana over the growing season. Fisheries and Marine Service Technical Report No. 561, 23 pp.

WHYTE, J.N.C. and ENGLAR, J.R., 1975(b). Composition of the non-metallic inorganic components of the marine alga Nereocystis luetkeana over the growing season. Fisheries and Marine Service Technical Report No. 568, 34 pp.

WHYTE, J.N.C. and ENGLAR, J.R., 1975(c). Basic organic chemical parameters of the marine alga Nereocystis luetkeana over the growing season. Fisheries and Marine Service Technical Report No. 589, 42 pp.

WOMERSLEY, H.B.S., 1954. The species of Macrocystis, with special reference to those on southern Australian coast. Univ. Calif. Publs. Bot., 27, 109.

YOUNG, E.G. and LANGILLE, W.M., 1958. The occurrence of inorganic elements in marine algae of the Atlantic provinces of Canada. Canadian Journal Bot., 36, 301.

TABLE 1

Dry Weight (Freeze Dried) and Ash Content
of *Macrocystis integrifolia* over the Growing Season

Month	Dry Weight (% Fresh Plant)	Ash (% Dry Weight) Total	Insoluble
April	9.75	37.1	7.0
May	12.75	42.6	8.1
June	12.55	36.5	5.9
July	11.75	36.3	4.9
August	14.47	37.9	6.4
September	13.95	41.6	8.1
October	13.16	43.9	8.0

TABLE 2

Major Elements in *Macrocystis integrifolia* over the Growing Season

Month	Elements (% Dry Weight)				
	K	Na	Mg	Ca	P
April	12.7	4.02	0.52	0.57	0.24
May	13.8	4.49	0.55	0.72	0.33
June	11.2	5.03	0.67	0.71	0.30
July	12.3	3.82	0.51	0.68	0.32
August	12.4	3.41	0.50	0.62	0.27
September	13.5	4.54	0.57	0.58	0.43
October	16.1	3.69	0.49	0.67	0.48

TABLE 3

Minor and Trace Elements in *Macrocystis integrifolia* over the Growing Season

Month	Elements (ppm Dry Weight)								
	Sr	B	Fe	Al	Zn	Ba	Mn	Cr	Cu
April	773	61	57	46	4	6	<4	<6	<2
May	775	80	42	38	4	6	<4	<6	<2
June	678	112	78	55	4	6	<4	<6	<2
July	621	85	72	48	2	6	<4	<6	<2
August	582	91	107	73	4	5	5	<6	<2
September	576	102	158	91	2	5	5	<6	<2
October	635	88	137	82	2	4	<4	<6	<2

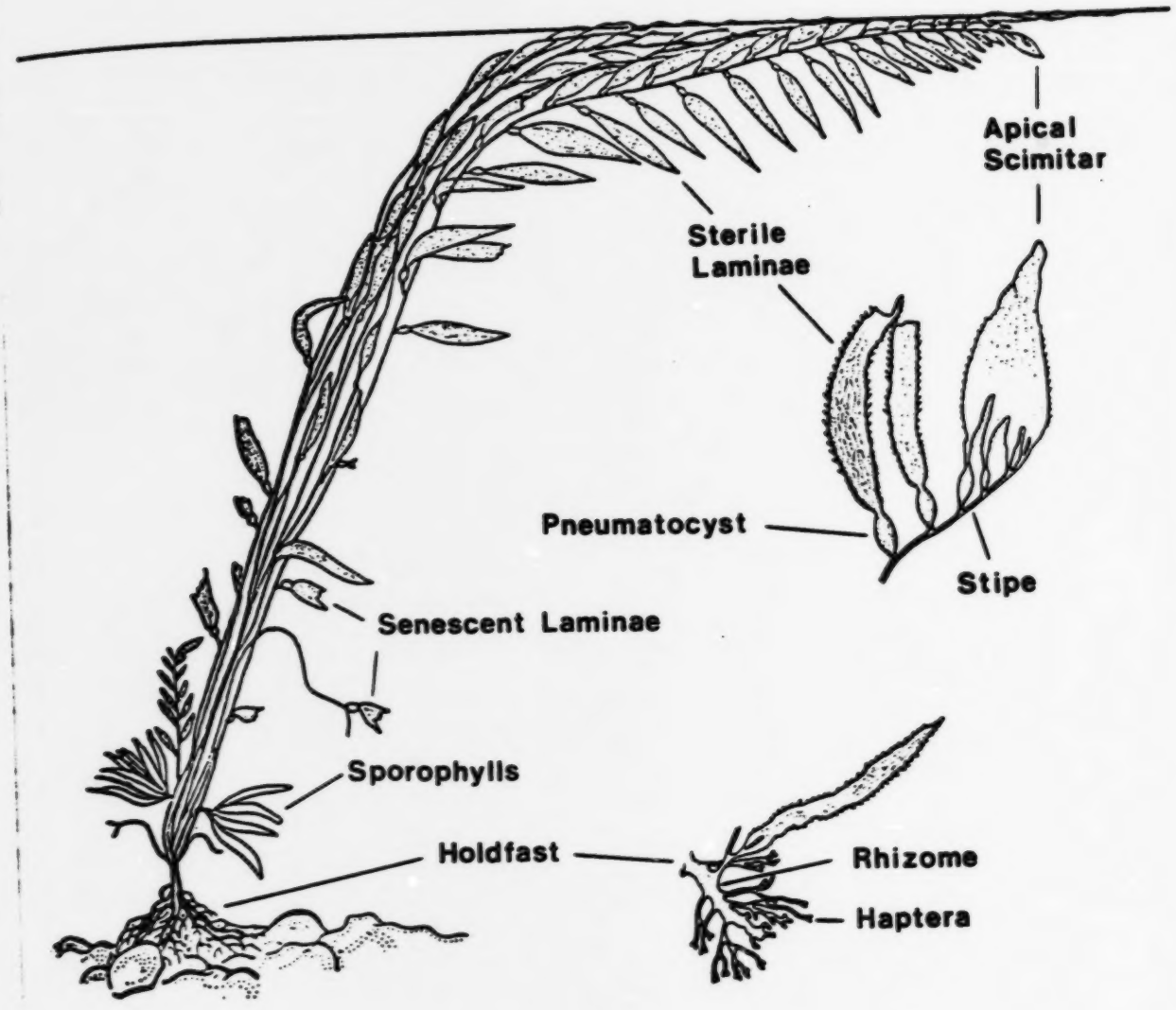
TABLE 4

Mean, Minimum and Maximum Concentrations of Elements in Macrocystis Over the Growing Season*

Elements	Mean	Range
Potassium, %	13.1	11.2 - 16.1
Sodium, %	4.14	3.41 - 5.03
Calcium, %	0.65	0.57 - 0.72
Magnesium, %	0.54	0.49 - 0.67
Phosphorus, %	0.34	0.24 - 0.48
Strontium, ppm	663	576 - 775
Iron, ppm	93	42 - 158
Boron, ppm	88	61 - 112
Aluminium, ppm	62	38 - 91
Barium, ppm	5	4 - 6
Zinc, ppm	3	2 - 4
Chromium, ppm	<6	0 - <6
Manganese, ppm	<4	< 4 - 5
Copper, ppm	<2	0 - <2
Cadmium, ppm	0.21	-
Lead, ppm	0.1	-
Cobalt, ppm	<0.2	-
Mercury, ppm	<0.05	-

* Absolutely dry weight basis.

Fig.1



Macrocystis integrifolia

Fig. 2

Percentage Freeze Dried Weight

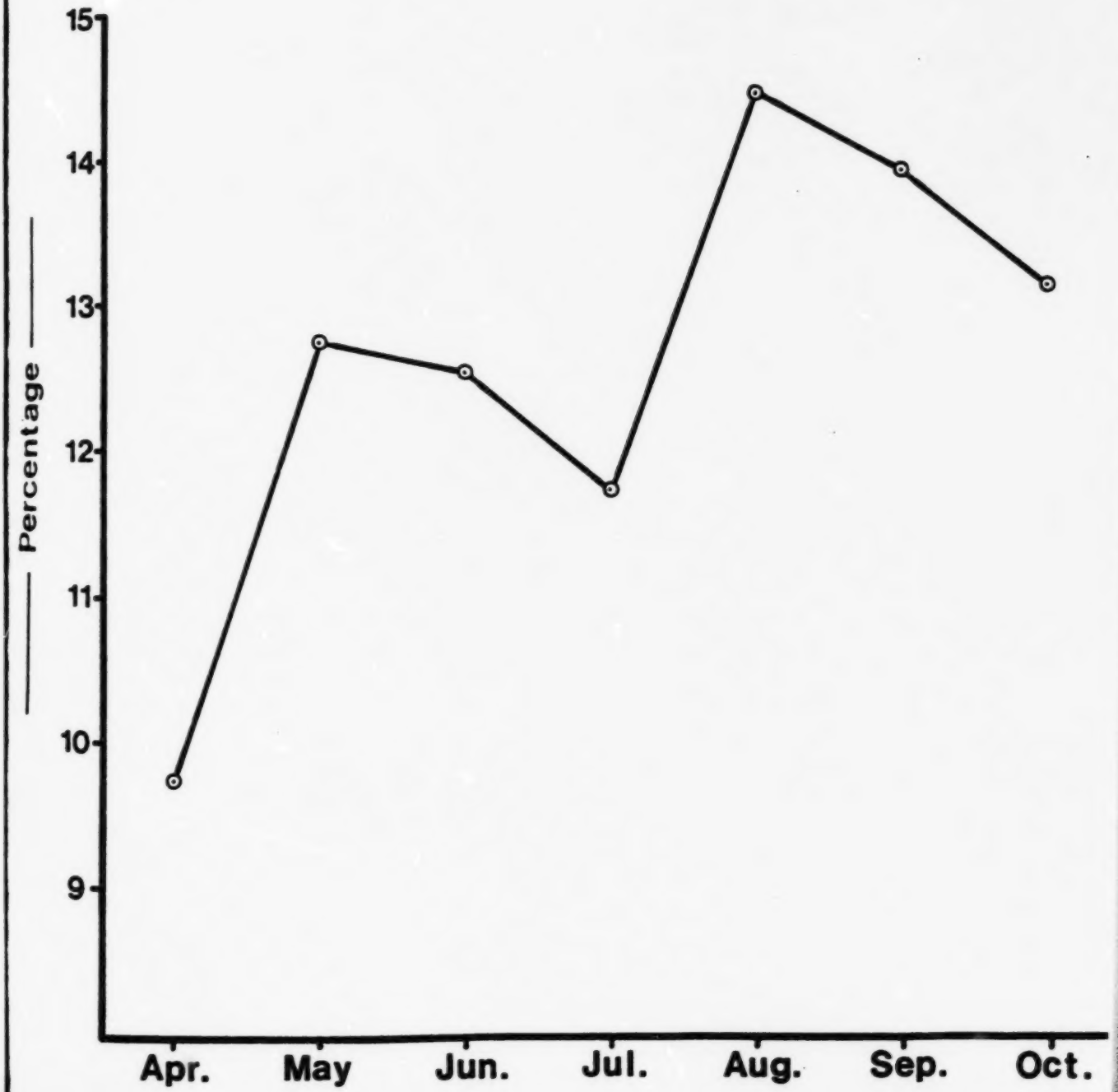


Fig.3

Ash Content

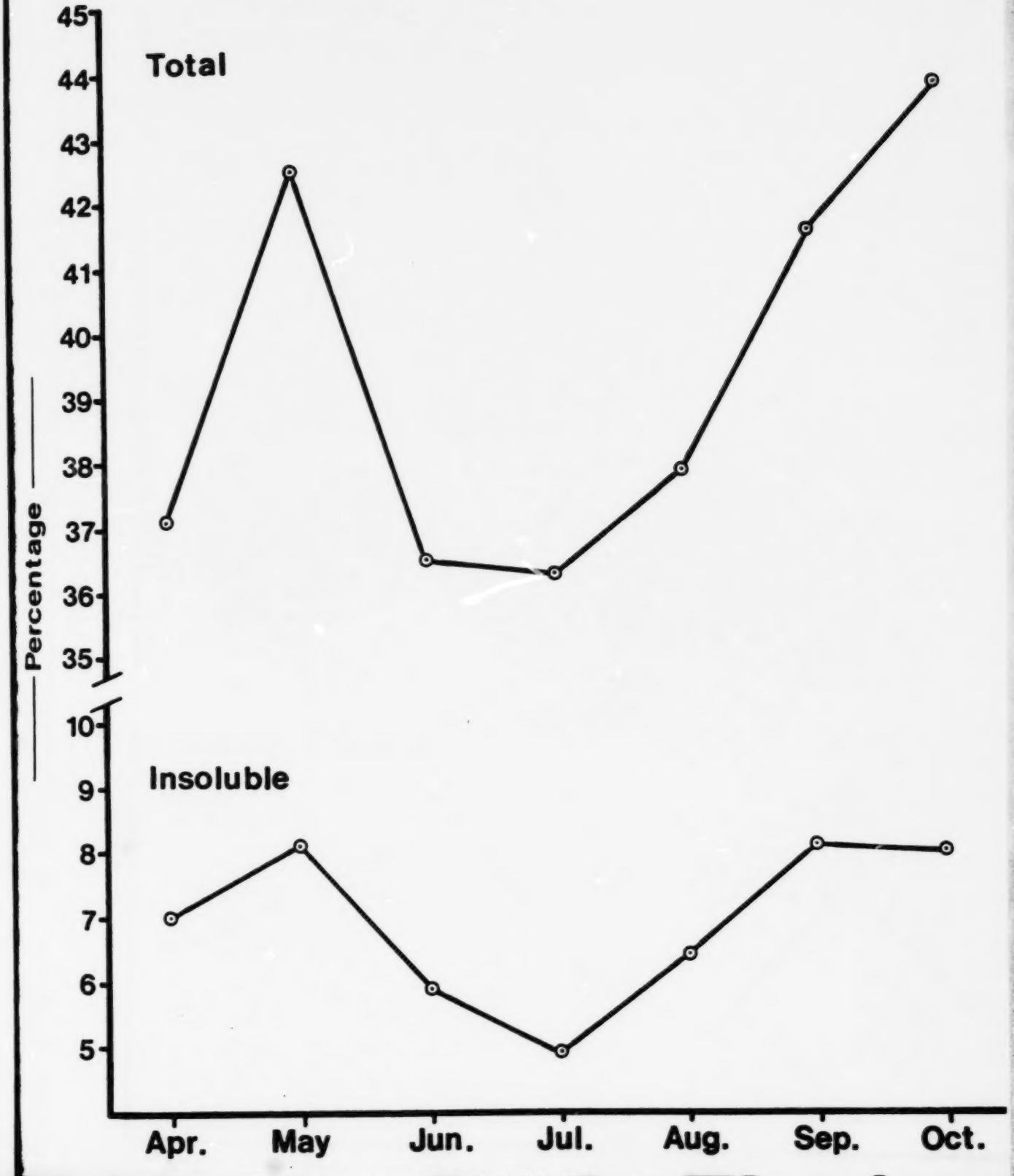


Fig.4

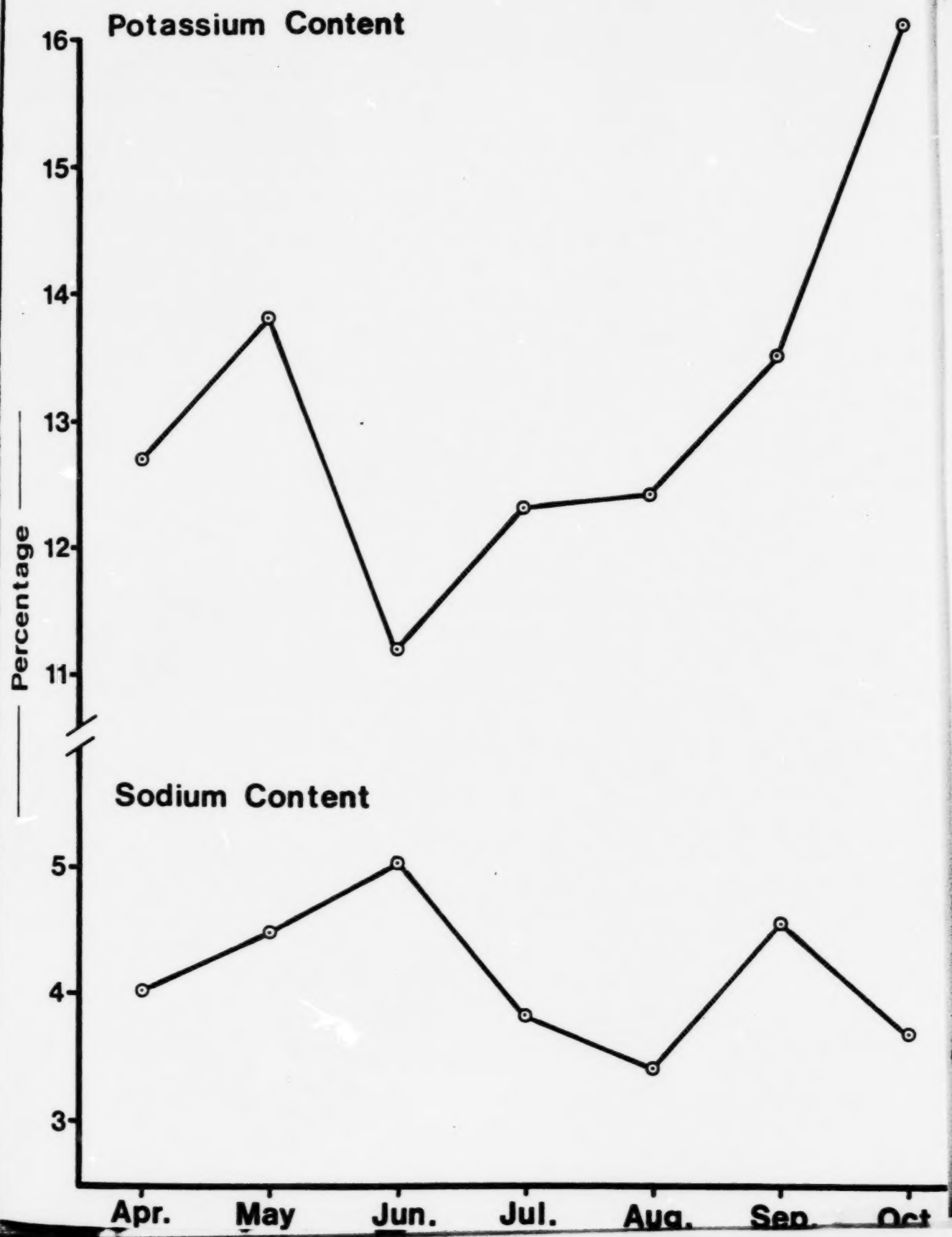

Potassium Content
16
15
14
13
12
11
Percentage
Sodium Content
5
4
3
Apr.
May
Jun.
Jul.
Aug.
Sep.
Oct

Fig.5

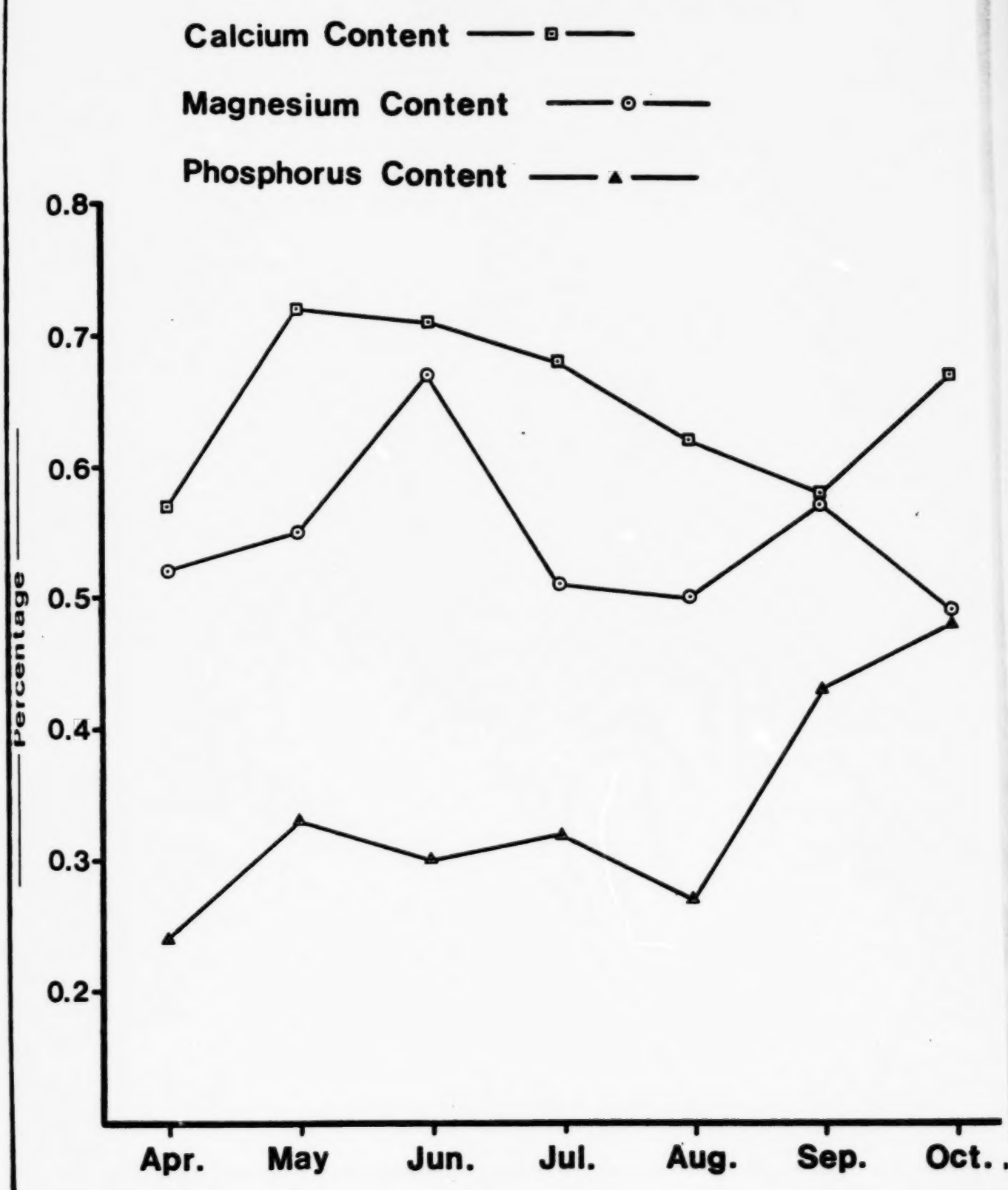

Calcium Content
Magnesium Content
Phosphorus Content
0.8
0.7
0.6
0.5
0.4
0.3
0.2
Percentage
Apr.
May
Jun.
Jul.
Aug.
Sep.
Oct.

Fig.6

Strontium Content

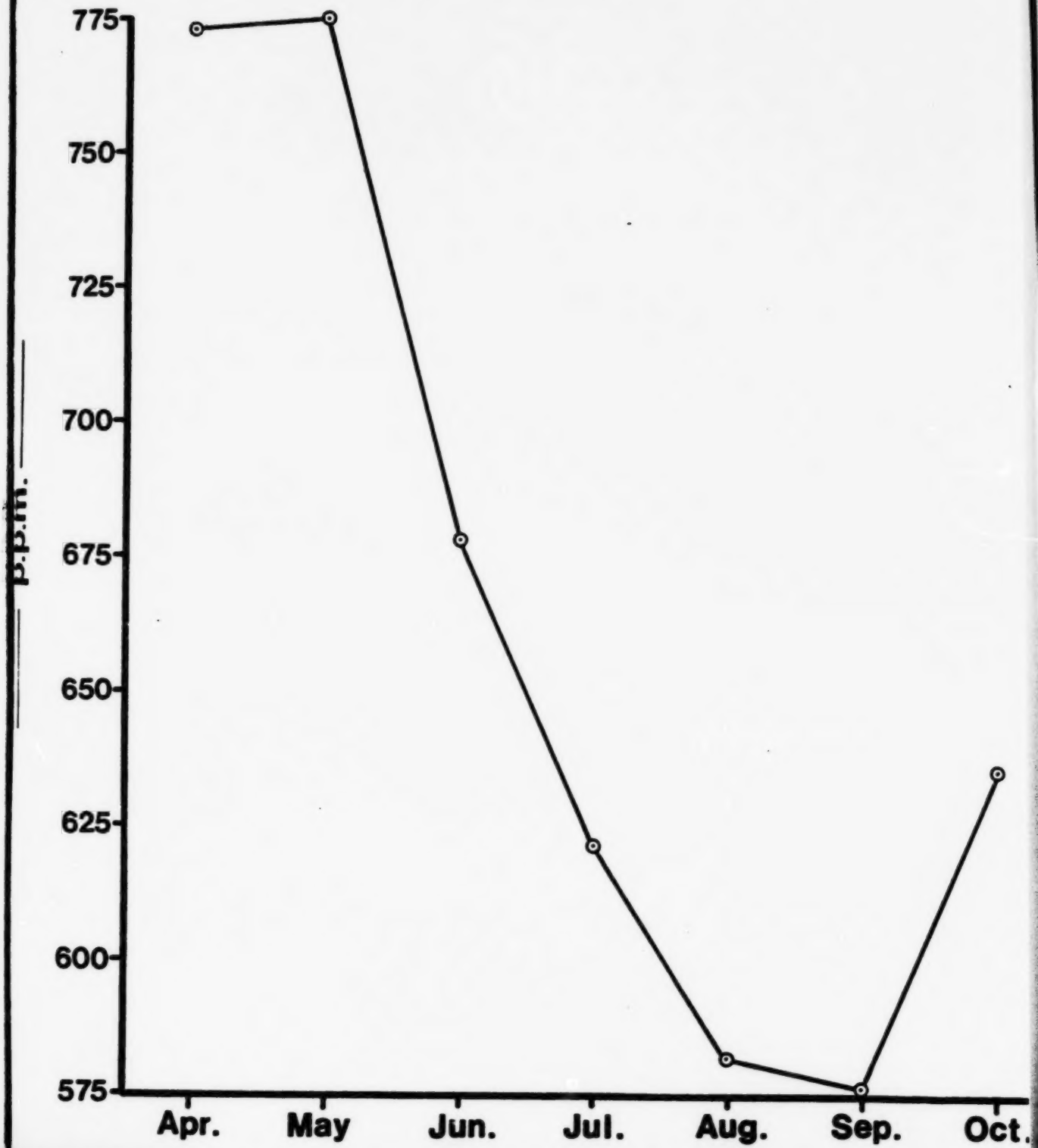
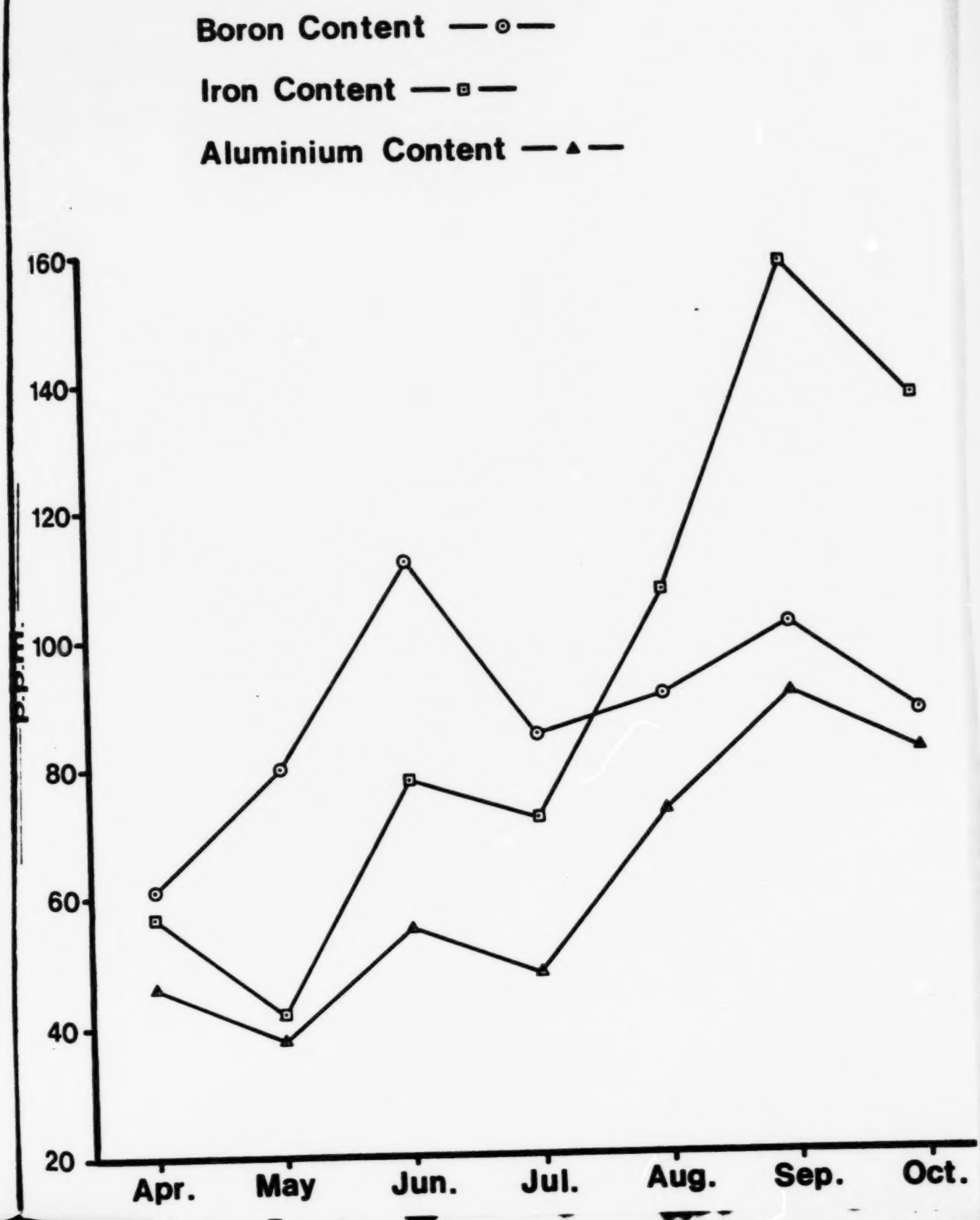


Fig.7


Boron Content
Iron Content
Aluminium Content
160
140
120
100
80
60
40
20
p.p.m.
Apr.
May
Jun.
Jul.
Aug.
Sep.
Oct.

POOR

QUALITY

ORIGINAL